AD-A151 743 DECOMPRESSION FROM SATURATION DIVES(U) DUKE UNIV MEDICAL CENTER DURHAM N C F G HALL LAB FOR ENVIRONMENTAL RESEARCH R D VANN 1984 N00014-84-C-0163 1/1

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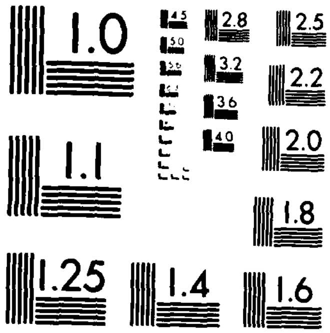
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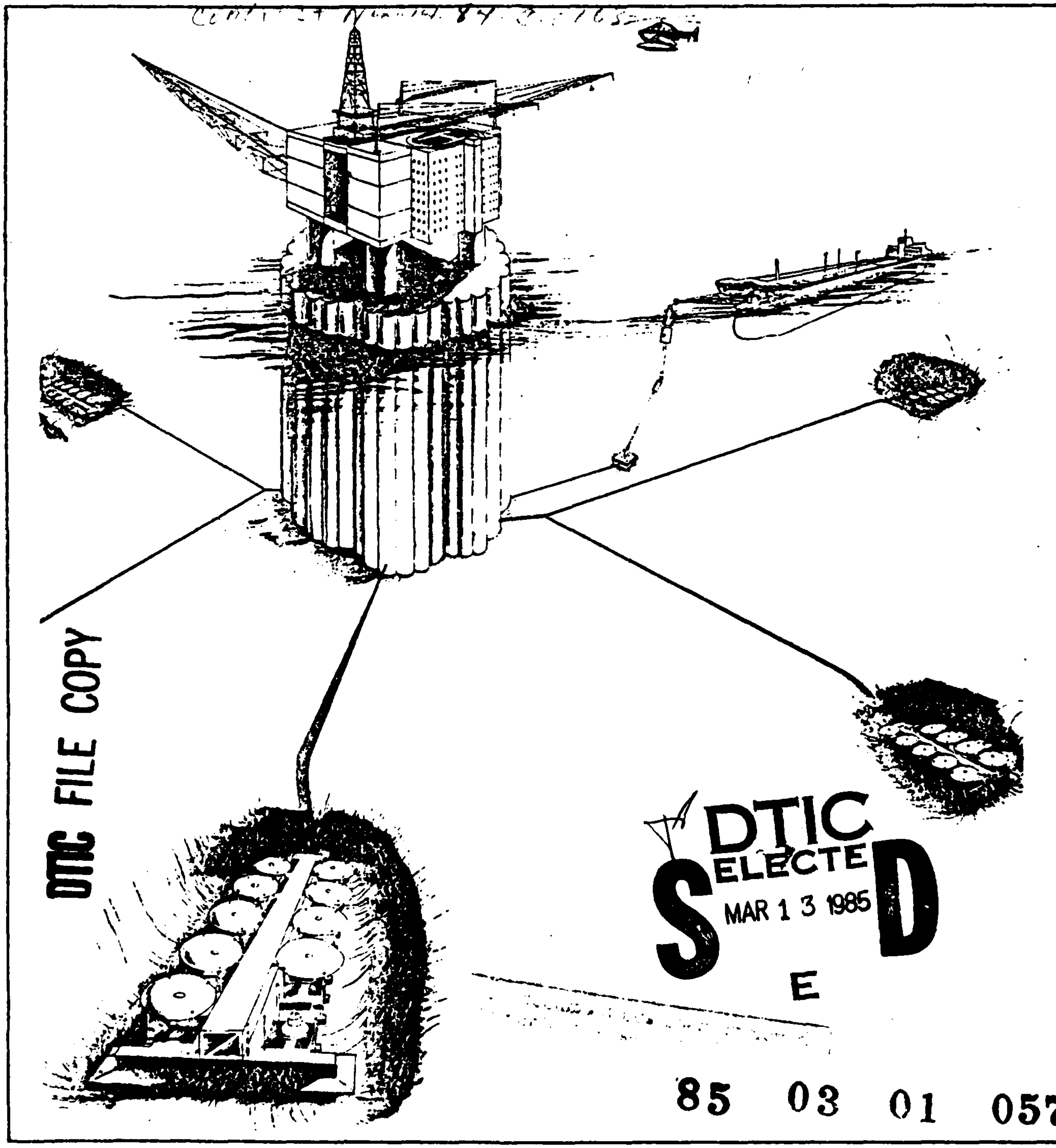
# PROCEEDINGS OF THE 3RD ANNUAL CANADIAN OCEAN TECHNOLOGY CONGRESS

MARCH 21-23, 1984
TORONTO, CANADA





Contract N00014-84-C-0163

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ADDRESS TO
THIRD ANNUAL
CANADIAN OCEAN TECHNOLOGY CONGRESS
TORONTO
MARCH 22, 1984

# DECOMPRESSION FROM SATURATION DIVES

During the early 1970's, about 20 helium-oxygen man-exposures were conducted at Duke University to depths of 720 to 1000 fsw for bottom times of up to 4 hours. Decompression took place on a modified Buhlmann schedule with an inspired oxygen partial pressure (PIO2) of 0.8 ATM. Decompression sickness was rare, but pulmonary oxygen toxicity forced a reduction in PIO2 to 0.6 ATM. In subsequent dives at this lower PIO2 with the same schedule, there was an increase in the incidence of decompression sickness, and it was found necessary to use slower rates of ascent.

Variations in the oxygen partial pressure were observed to have similar effects in England during the mid-1970's at the Royal Navy Physiological Laboratory (Vorosmarti, Hanson, and Barnard 1978). Decompression schedules for saturation dives to 180 meters and deeper were found to cause bends when the oxygen partial pressure was 0.22 ATM. The same or similar schedules were safe, however, when the oxygen partial pressure was raised to 0.4 ATM.

References to the importance of the oxygen partial pressure in decompression can be found elsewhere in the literature. In the mid-1960's at Buffalo, Van Liew showed that the inert gas elimination rate from gas pockets in animals was proportional to the oxygen partial pressure (Van Liew et al. 1965). The decompression theories of Workman and Schreiner also predicted that the rate of ascent from a saturation dive is proportional, to the oxygen partial pressure (Workman 1969; Schreiner and Kelley 1967). Let us begin with this assumption, and see to where it leads.

If the rate of ascent R from a saturation dive is directly proportional to the inspired oxygen partial pressure PIO2, then

$$R = K*PIO2$$

where R is measured in fsw per hour (fph), PIO2 is measured in ATM, and the proportionality constant K is in fph/ATM. By integrating this relationship, decompression schedules can be found for both constant oxygen percentage and constant oxygen partial pressure dives. If the oxygen partial pressure is constant, the depth is a linear function of time, or

$$D(t) = Ds - K*PIO2*t$$

DR. A.E. COLLIN
Dr Collin initially joined the

where Ds is the saturation depth in fsw, and t is time in hours. If the inspired oxygen fraction (FIO2) is constant, the depth is an exponential function of time, or

$$D(t) = (Ds + 33)*\exp(-K*FIO2*t/33) - 33 \text{ fsw}$$

According to this method, therefore, saturation decompression schedules are completely determined by the constant K.

While there is presently no procedure for predicitng the value of K theortetically, an empirically estimated value, Ke, may be determined for any saturation dive conducted in the past. For example, Ke is given by

$$Ke = \frac{Ds - Ddcs}{PIO2*T}$$

for a schedule which uses a constant oxygen partial pressure where Ddcs is the depth at which symptoms of decompression sickness first occur (or the surface if they did not occur), and T is the travel time in hours between the saturation depth Ds and the depth of symptoms Ddcs. When FIO2 is constant,

$$Ke = -\frac{33}{FIO2*T} * \ln\frac{Ddcs + 33}{Ds + 33}$$

The error of these estimates depends upon how far a schedule deviates from the linear or exponential ideals. For schedules which use both constant PIO2 and constant FIO2, a time-weighted average value is calculated.

This procedure was used to define the decompression schedule for the Atlantis III dive at Duke. A search of the published literature and of laboratory reports revealed the results of 579 helium-oxygen man-decompressions. After determining the corresponding values of Ke for each of these dives, it was found that decompression sickness had occurred only when Ke was greater that 10 fph/ATM (Vann and Dick 1981). A K-value of 8 fph/ATM was used for Atlantis III which reached a depth of 2250 fsw. At a PIO2 of 0.5 ATM, this gave an ascent rate of 4 fph which resulted in Type I decompression sickness is 2 of the 3 divers at 1736 and 1706 fsw.

The breathing gas for Atlantis III contained 10% nitrogen, and it was initially concluded that this nitrogen was responsible for the decompression sickness which occurred. During Atlantis IV, however, with 5% nitrogen and a maximum depth of 2132 fsw, Type I decompression sickness occurred at 1412 fsw in 1 of 3 divers with a K-value of 5.2 fph/ATM and an average ascent rate of 2.6 fph. These

results suggested that it was the dive depth - and not the nitrogen percentage - which was responsible for the decompression sickness. They also suggested that it might be necessary to reduce the value of K as the maximum depth of the dive increased. A similar depth effect appears to exist for decompression from nitrogen-oxygen saturation dives (Barry, Vann, Youngblood, Peterson, and Bennett 1984).

The effect of depth on the magnitude of K has been evaluated for 1055 helium-oxygen man-decompressions during which there were 104 cases of decompression sickness. These results are shown in Fig. 1. The solid line is an estimate of how the safe value of K might decrease with increasing saturation depth. The points above the line represent schedules with at least one case of decompression sickness. The points below the line represent schedules with at least 30 trials and no decompression sickness (48, 490, and 33 trials for these schedules). The reliability of schedules with fewer trials is questionable because of statistical uncertainty.

In Fig. 2, the helium-oxygen results are shown with the results of 189 nitrogen-oxygen man-decompressions during which there were 38 cases of decompression sickness. As before, the solid lines are estimates of how K might vary with depth, and the points above this line represent scheduled with at least on case of decompression sickness. There were no nitrogen-oxygen schedules with at least 30 trials in which there was no decompression sickness.

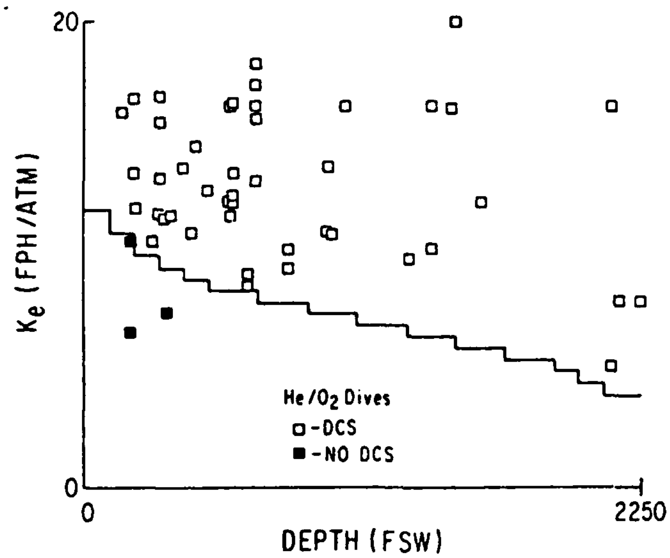
Why might it be that the ascent rate would need to be reduced as the saturation depth increased? Let us assume that undissolved gas is the cause of decompression sickness and that undissolved gas is produced at a nearly constant rate during a linear decompression. The volume of gas released during decompression from a deep dive, then, would be larger than the volume released during a shorter decompression at the same ascent rate from a shallow dive. A decrease in the ascent rate would be necessary to reduce this gas volume.

It may be premature to state with certainty that the ascent rate should decrease as the saturation depth increases, but this conclusion is strongly suggested by practical experience. This same experience may be used empirically to develop saturation decompression schedules. Tables 1 to 4 give schedules for helium-oxygen dives from 2250 fsw (686 msw) and for nitrogen-oxygen dives from

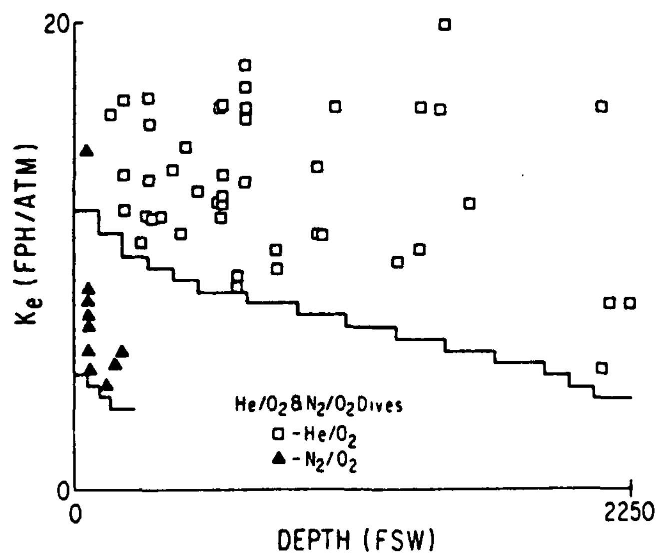
200 fsw (60 msw). These schedules were generated from the estimated K-lines shown in Fig. 2. The PIO2 is held at 0.5 ATM from the maximum depth to 45 fsw (14 msw) after which the FiO2 is held at 0.21 until surfacing. While the FIO2 is constant, the ascent rate is reduced to compensate for the falling oxygen partial pressure. For convenience, the ascent rate is reduced at 15 or 10 fsw intervals to the rate required by the lowest PIO2 in the interval. For helium-oxygen diving, nitrogen is limited to not more than 5% deeper than 500 fsw (150 msw) and not more than 0.79 ATM shallower than 500 fsw. Should decompression sickness occur on any dive, a slower schedule can be calculated by reducing the magnitude of Ke. This method is simple and relies only on previous experience, but it cannot guarantee the most efficient schedules.

ACKNOWLEDGEMENT

This work was conducted with continuing support from the Office of Naval Research and the Naval Medical Research and Development Command.




1. The variation of Ke with depth for helium-oxygen saturation decompression. The open squares represent dives with at least one case of decompression sickness, and the closed squares represent dives with at least 33 safe trials. The solid line is an estimate of how the safe value of Ke might vary with depth.




2. The variation of Ke with depth for helium-oxygen and nitrogen-oxygen saturation decompression. The open squares represent helium-oxygen dives with at least one case of decompression sickness, and the closed triangles represent nitrogen-oxygen dives with at least one case of decompression sickness. The solid lines are estimates of how the safe value of Ke might vary with depth for both gas mixtures.

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TABLE 1. PROVISIONAL HE/O2 SATURATION DECOMPRESSION SCHEDULES (FSW)

OXYGEN - 0.5 ATM PARTIAL PRESSURE DEEPER THAN 45 FSW
- 21 % FROM 45 FSW TO SURFACE
NITROGEN - NOT MORE THAN 5 % DEEPER THAN 500 FSW
- NOT MORE THAN 0.79 ATM PARTIAL PRESSURE AT LESS THAN 500 FSW
HELIUM - BALANCE

| SATURATION DEPTH, FSW | KE, FPH/ATM | RATE OF ASCENT, MIN/FSW | | | | | DECOMPRESSION TIME | | |
|---|---|---|---|---|---|---|---|---|---|
| | | UNTIL 45 FSW | 45 TO 30 FSW | 30 TO 20 FSW | 20 TO 10 FSW | 10 TO 0 FSW | DAY | HR | MIN |
| 0 - 100 | 12.0 | 11 | 13 | 15 | 19 | 24 | 0 | 23 | 0 |
| 100 - 200 | 11.0 | 11 | 14 | 17 | 20 | 26 | 1 | 18 | 25 |
| 200 - 300 | 10.0 | 13 | 15 | 18 | 22 | 29 | 2 | 22 | 30 |
| 300 - 400 | 9.5 | 13 | 16 | 19 | 24 | 31 | 3 | 21 | 15 |
| 400 - 500 | 9.0 | 14 | 17 | 20 | 25 | 32 | 5 | 3 | 15 |
| 500 - 600 | 8.5 | 15 | 18 | 21 | 26 | 34 | 6 | 12 | 45 |
| 600 - 700 | 8.5 | 15 | 18 | 21 | 26 | 34 | 7 | 13 | 45 |
| 700 - 800 | 8.0 | 16 | 19 | 23 | 28 | 36 | 9 | 4 | 35 |
| 800 - 900 | 8.0 | 16 | 19 | 23 | 28 | 36 | 10 | 7 | 15 |
| 900 - 1000 | 7.5 | 17 | 20 | 24 | 30 | 39 | 12 | 3 | 5 |
| 1000 - 1100 | 7.5 | 17 | 20 | 24 | 30 | 39 | 13 | 7 | 25 |
| 1100 - 1200 | 7.0 | 18 | 22 | 26 | 32 | 41 | 15 | 8 | 30 |
| 1200 - 1300 | 7.0 | 18 | 22 | 26 | 32 | 41 | 16 | 14 | 30 |
| 1300 - 1400 | 6.5 | 19 | 24 | 28 | 34 | 44 | 18 | 20 | 45 |
| 1400 - 1500 | 6.5 | 19 | 24 | 28 | 34 | 44 | 20 | 4 | 25 |
| 1500 - 1600 | 6.0 | 21 | 25 | 30 | 37 | 48 | 23 | 17 | 40 |
| 1600 - 1700 | 6.0 | 21 | 25 | 30 | 37 | 48 | 25 | 4 | 40 |
| 1700 - 1800 | 5.5 | 22 | 28 | 33 | 40 | 52 | 27 | 23 | 20 |
| 1800 - 1900 | 5.5 | 22 | 28 | 33 | 40 | 52 | 29 | 12 | 0 |
| 1900 - 2000 | 5.0 | 25 | 30 | 36 | 44 | 58 | 35 | 5 | 5 |
| 2000 - 2100 | 4.5 | 27 | 34 | 40 | 49 | 64 | 39 | 22 | 45 |
| 2100 - 2250 | 4.0 | 31 | 38 | 45 | 55 | 72 | 49 | 1 | 25 |

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TABLE 2. PROVISIONAL HE/O2 SATURATION DECOMPRESSION SCHEDULES (MSW)

OXYGEN - 0.5 ATM PARTIAL PRESSURE DEEPER THAN 14 MSW
- 21 % FROM 14 MSW TO SURFACE

NITROGEN - NOT MORE THAN 5 % DEEPER THAN 150 MSW
- NOT MORE THAN 0.79 ATM PARTIAL PRESSURE AT LESS THAN 150 MSW

HELIUM - BALANCE

| SATURATION DEPTH, MSW | KE, FPH/ ATM | RATE OF ASCENT, MIN/(.5 MSW) | | | | | DECOMPRESSION TIME | | |
|---|---|---|---|---|---|---|---|---|---|
| | | UNTIL 14 MSW | 14 TO 9 MSW | 9 TO 6 MSW | 6 TO 3 MSW | 3 TO 0 MSW | DAY | HR | MIN |
| 0 - 30 | 12.0 | 17 | 21 | 25 | 30 | 40 | 0 | 22 | 4 |
| 30 - 60 | 11.0 | 18 | 23 | 27 | 33 | 43 | 1 | 17 | 44 |
| 60 - 90 | 10.0 | 20 | 25 | 30 | 36 | 47 | 2 | 18 | 8 |
| 90 - 120 | 9.5 | 21 | 26 | 31 | 38 | 50 | 3 | 18 | 26 |
| 120 - 150 | 9.0 | 22 | 28 | 33 | 40 | 53 | 4 | 21 | 0 |
| 150 - 180 | 8.5 | 24 | 29 | 35 | 43 | 56 | 6 | 7 | 2 |
| 180 - 210 | 8.5 | 24 | 29 | 35 | 43 | 56 | 7 | 7 | 2 |
| 210 - 240 | 8.0 | 25 | 31 | 37 | 45 | 59 | 8 | 15 | 36 |
| 240 - 270 | 8.0 | 25 | 31 | 37 | 45 | 59 | 9 | 16 | 36 |
| 270 - 300 | 7.5 | 27 | 33 | 39 | 48 | 63 | 11 | 13 | 54 |
| 300 - 330 | 7.5 | 27 | 33 | 39 | 48 | 63 | 12 | 16 | 54 |
| 330 - 360 | 7.0 | 29 | 36 | 42 | 52 | 67 | 14 | 20 | 34 |
| 360 - 390 | 7.0 | 29 | 36 | 42 | 52 | 67 | 16 | 1 | 34 |
| 390 - 410 | 6.5 | 31 | 38 | 45 | 56 | 73 | 18 | 0 | 56 |
| 410 - 450 | 6.5 | 31 | 38 | 45 | 56 | 73 | 19 | 18 | 16 |
| 450 - 480 | 6.0 | 33 | 41 | 49 | 60 | 79 | 22 | 10 | 14 |
| 480 - 510 | 6.0 | 33 | 41 | 49 | 60 | 79 | 23 | 19 | 14 |
| 510 - 540 | 5.5 | 36 | 45 | 54 | 66 | 86 | 27 | 11 | 18 |
| 540 - 570 | 5.5 | 36 | 45 | 54 | 66 | 86 | 28 | 23 | 18 |
| 570 - 600 | 5.0 | 40 | 50 | 59 | 72 | 94 | 33 | 20 | 10 |
| 600 - 630 | 4.5 | 44 | 55 | 65 | 80 | 105 | 39 | 1 | 38 |
| 630 - 686 | 4.0 | 50 | 62 | 73 | 90 | 118 | 48 | 6 | 26 |

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TABLE 3. PROVISIONAL N2/O2 SATURATION DECOMPRESSION SCHEDULES (FSW)

OXYGEN - 0.5 ATM PARTIAL PRESSURE DEEPER THAN 45 FSW
- 21 % FROM 45 FSW TO SURFACE

| SATURATION DEPTH, FSW | KE, FPH/ ATM | RATE OF ASCENT, MIN/FSW UNTIL 45 FSW | 45 TO 30 FSW | 30 TO 20 FSW | 20 TO 10 FSW | 10 TO 0 FSW | DECOMPRESSION TIME DAY | HR | MIN |
|---|---|---|---|---|---|---|---|---|---|
| 0 - 40 | 5.0 | -- | 30 | 36 | 44 | 58 | 1 | 4 | 25 |
| 40 - 50 | 5.0 | 25 | 30 | 36 | 44 | 58 | 1 | 8 | 35 |
| 50 - 60 | 4.5 | 27 | 34 | 40 | 49 | 64 | 1 | 16 | 45 |
| 60 - 70 | 4.5 | 27 | 34 | 40 | 49 | 64 | 1 | 21 | 15 |
| 70 - 80 | 4.5 | 27 | 34 | 40 | 49 | 64 | 2 | 1 | 45 |
| 80 - 90 | 4.5 | 27 | 34 | 40 | 49 | 64 | 2 | 6 | 15 |
| 90 - 100 | 4.5 | 27 | 34 | 40 | 49 | 64 | 2 | 10 | 45 |
| 100 - 110 | 4.0 | 31 | 38 | 45 | 55 | 72 | | 23 | 45 |
| 110 - 120 | 4.0 | 31 | 38 | 45 | 55 | 72 | 3 | 4 | 55 |
| 120 - 130 | 4.0 | 31 | 38 | 45 | 55 | 72 | 3 | 10 | 5 |
| 130 - 140 | 4.0 | 31 | 38 | 45 | 55 | 72 | 3 | 15 | 15 |
| 140 - 150 | 4.0 | 31 | 38 | 45 | 55 | 72 | | 20 | 25 |
| 150 - 160 | 3.5 | 35 | 43 | 51 | 63 | 82 | 4 | 14 | 30 |
| 160 - 170 | 3.5 | 35 | 43 | 51 | 63 | 82 | 4 | 20 | 20 |
| 170 - 180 | 3.5 | 35 | 43 | 51 | 63 | 82 | 5 | 2 | 10 |
| 180 - 190 | 3.5 | 35 | 43 | 51 | 63 | 82 | 5 | 8 | 0 |
| 190 - 200 | 3.5 | 35 | 43 | 51 | 63 | 82 | 5 | 13 | 50 |

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TABLE 4. PROVISIONAL N2/O2 SATURATION DECOMPRESSION SCHEDULES (MSW)

OXYGEN - 0.5 ATM PARTIAL PRESSURE DEEPER THAN 14 MSW
- 21 % FROM 14 MSW TO SURFACE

| SATURATION DEPTH, MSW | KE, FPH/ ATM | RATE OF ASCENT, MIN/(.5 MSW) | | | | | DECOMPRESSION TIME | | |
|---|---|---|---|---|---|---|---|---|---|
| | | UNTIL 14 MSW | 14 TO 9 MSW | 9 TO 6 MSW | 6 TO 3 MSW | 3 TO 0 MSW | DAY | HR | MIN |
| 0 - 12 | 5.0 | -- | 50 | 59 | 72 | 94 | 1 | 4 | 10 |
| 12 - 15 | 5.0 | 40 | 50 | 59 | 72 | 94 | 1 | 8 | 10 |
| 15 - 18 | 4.5 | 44 | 55 | 65 | 80 | 105 | 1 | 16 | 2 |
| 18 - 21 | 4.5 | 44 | 55 | 65 | 80 | 105 | 1 | 20 | 26 |
| 21 - 24 | 4.5 | 44 | 55 | 65 | 80 | 105 | 2 | 0 | 50 |
| 24 - 27 | 4.5 | 44 | 55 | 65 | 80 | 105 | 2 | 5 | 14 |
| 27 - 30 | 4.5 | 44 | 55 | 65 | 80 | 105 | 2 | 9 | 38 |
| 30 - 34 | 4.0 | 50 | 62 | 73 | 90 | 118 | 2 | 23 | 46 |
| 34 - 37 | 4.0 | 50 | 62 | 73 | 90 | 118 | 3 | 4 | 46 |
| 37 - 40 | 4.0 | 50 | 62 | 73 | 90 | 118 | 3 | 9 | 46 |
| 40 - 43 | 4.0 | 50 | 62 | 73 | 90 | 118 | 3 | 14 | 46 |
| 43 - 46 | 4.0 | 50 | 62 | 73 | 90 | 118 | 3 | 19 | 46 |
| 46 - 49 | 3.5 | 57 | 71 | 84 | 103 | 134 | 4 | 14 | 26 |
| 49 - 52 | 3.5 | 57 | 71 | 84 | 103 | 134 | 4 | 20 | 8 |
| 52 - 55 | 3.5 | 57 | 71 | 84 | 103 | 134 | 5 | 1 | 50 |
| 55 - 58 | 3.5 | 57 | 71 | 84 | 103 | 134 | 5 | 7 | 32 |
| 58 - 61 | 3.5 | 57 | 71 | 84 | 103 | 134 | 5 | 13 | 14 |

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DISCUSSION FOLLOWING DR. VANN

Looking at Figure 1, it was pointed out that the line dividing saturation dives resulting in bends from those that were bends free received a lot of its slope from one point at about 2200 fsw. Dr. Vann responded that nitrox decompressions (Figure 2) yield about the same value of K, and that there is a definite trend established from the shallow dives where more data exists. He feels that more data are needed; there are limited data for deep dives with no decompression sickness, so it is not really possible to set the lower limit for the line. The Moderator acknowledged that the principal was valid, that the deeper one starts a saturation decompression the slower the ascent rate. It was also noted that some controversy still exists over whether the nitrogen content in the Atlantis dives was the cause of the decompression sickness that occurred at such deep depths. Atlantis 3 had 10% nitrogen, which turned out to be too much in terms of narcosis; 5% is better for that depth range.

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